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The Identification of War-fighting Symbology With the Use of a Small Display

by Kimberly Myles

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14. ABSTRACT
Two studies were conducted to evaluate the effects of symbol size and screen clutter on symbol identification when one is using a small map display. The purpose of the first study was to determine the minimum threshold symbol size for a group of selected war-fighting symbols that could be discriminated and identified on a 3.5-inch simulated wrist map display. The Best PEST (Parameter Estimation by Sequential Testing) psychophysical adaptive procedure was used to obtain symbol size thresholds for a no-map and map environment with 20 active-duty Soldiers. A True Type font of 16 points was found as the minimum symbol size at which 95% of the responses were predicted to be accurate. The second study aimed to determine the number of symbols (defined as clutter) that could be displayed on the 3.5-inch display, when one is using a rural and urban map display, without significant decreases in performance. Eight active-duty Soldiers determined if target symbols were present on or absent from map images containing distractor symbols. Performance was measured via scan time and response accuracy. For the urban map display only, mean scan times began to increase at the clutter level of nine symbols and continued to increase at a clutter level of 12 symbols. A response accuracy of 92% was obtained with incorrect responses falling randomly across treatments. These results show that a symbol size of 16 points is adequate for symbol identification when the symbol is embedded on a 3.5-inch map display. Also, if the map background does not perceptibly contribute to display clutter, superimposing as few as three or as many as 12 symbols over the map will yield no change in scan time for a target symbol. Based on these findings, it is reasonable that the symbol information that Soldiers retrieve from this display will be legible and organized, which will help to increase the Soldier's situational understanding of his environment and decrease the amount of time the Soldier devotes to gathering information for critical decision making.

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screen clutter; small display; symbol detection threshold; symbol size

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1. Introduction

Physical effort is not the sole component for winning conflicts. Cognitive effort, although not a directly visible measure, is as equally important as physical effort. Admiral Arthur Cebrowski, Director of Force Transformation, states a similar premise, "…battles are won and lost in the minds of commanders…" (Department of Defense [DoD], 2004, p. 3). Physical strength and endurance are important for task and mission completion. However, without sufficient information to facilitate smart decisions, the Soldier's resulting physical effort will be comparable to performing a physical task with his eyes closed. Therefore, the Soldier will be unable to view and process past and current situation cues that would enable insight about what is expected to happen next (Endsley, 1995). Insight about what is about to happen can only be achieved if a person has complete and accurate information about his current environment. In embracing this viewpoint, the DoD initiated a "force transformation" with one aspect involving moving battlefield information from the commander level down to the individual Soldier level (DoD, 2004). Real-time information production, updates, and exchange unimpeded by location will help to enhance decision-making strategies at the individual Soldier level. The ideal situation will be that everyone on the battlefield will be able to retrieve needed information from a networked information system. This information connection will prepare Soldiers to fight "smart"[1] battles to complement the physical battle. Information technology (IT) features consisting of distributed systems on interconnected networks and support of autonomous users seen in the business sector will be a viable solution in helping Soldiers to fight "smart" battles (Christie, Scane, & Collyer, 1995; DoD, 2004).

IT advancements in autonomous computer use will significantly impact the information networking capabilities of the dismounted infantry Soldier. The dismounted Soldier is most likely to maneuver around the battlefield in response to situation changes on foot rather than in a vehicle. Thus, the current dismounted Soldier is the most "disconnected" from battle information updates (DoD, 2004). Trends in small, lightweight, easy-to-carry computers such as "palmtops" will give the future dismounted Soldier access to information gathering resources while "working on the move" (Christie et al., 1995). An Army system with such capability is Land Warrior (LW). "The Land Warrior system is a first-generation, integrated fighting system that includes everything an infantry Soldier wears or carries on the battlefield" (Gourley, 2004). The helmet-mounted display (HMD) is the LW component that will allow a visual link to battlefield information during Soldier movement. The HMD is a visual display that is mounted to the Soldier's helmet and can be flipped up and down as needed to access a variety of battlefield information. For example, digital maps display the current location of friends, enemies, and troop movements on the battlefield (National Research Council, 1997). This digitized information will provide the Soldier with a

[1]A "smart" battle requires the gathering of as much information as possible and the ability to understand all consequences associated with the information. This advantage prepares the Soldier to plan potential strategies while preserving resources (e.g., manpower, equipment, etc.).

“total” picture of the working environment which expands the Soldier’s understanding of the battlefield beyond his immediate visual environment. Operating with a “total” or complete picture will enhance the Soldier’s state of situational awareness (SA) and prepare him to make smart decisions about what to do next. However, new technologies intended to increase performance can sometimes produce the opposite effect. For example, the HMD is designed to increase SA by providing a broader visual picture of the battlefield, but it may also reduce SA by obstructing some parts of the visual field. The National Research Council (1997) has reported that although the HMD is more than adequate in providing battlefield updates when needed, it can partially occlude the Soldier’s natural view of the environment.

Soldier systems that emerged under the Future Force Warrior (FFW) program improved and furthered the technologies initiated by the LW system concept. FFW communication systems (now merged with LW) are being designed to enhance the Soldier’s situational understanding of his environment, with an emphasis on team-unit networked communications (U.S. Army Natick Soldier Center, 2005). All individuals within a team receive similar battlefield information, which helps to support a team-centered view of situational understanding. A wrist-mounted display (perhaps in place of or in addition to an HMD for select personnel) is proposed to facilitate a team-centered view of the battlefield through the shared display of navigational tasks, status, and location indicators for friendly, enemy, and fellow unit individuals via the use of digital maps. The small area of the wrist will mandate that the wrist-mounted display be small, which is ideal for a dismounted Soldier. However, as the size of a display decreases, text and graphics and functional screen space will also decrease (Wickens & Rose, 2001). Battlefield information is primarily communicated via symbols, and for a number of digital military systems, symbol size and display size have been shown to impact visual capability and performance. For example, several Army systems have documented complaints that symbols are difficult to see because of small display sizes and because map screens become too busy as the number of symbols increases, as collected from Soldiers via system evaluation studies and surveys. Durbin and Armstrong (2000) assessed three medium-sized moving map display systems for Army pilots. For one system, 60% of the pilots reported that the screen size was ineffective for displaying data. Pilots suggested the use of a larger screen. For two of the three systems, pilots reported that symbols were difficult to understand because of their size. Conversely, screen clutter appears to be one of the complaints associated with the LW HMD. Carstens (2004) found that as the number of symbols increased on the LW HMD, Soldiers perceived the screen as too busy. Furthermore, Barnes (2003) explains that many digital map displays are small, which causes symbols to cover too much map area, which “…occludes neighboring symbols and gives the commander only an approximate location of a particular unit” (p. 9).

Design efforts to efficiently use available screen space may lead to the creation of smaller information elements in order to fit all required information within a reduced space. This may result in symbols that are too small to resolve visually and screen crowding (Lindberg & Näsänen, 2003). Jacko et al. (2002) studied the visual search strategies of computer users with

age-related macular degeneration (AMD) and computer users without AMD. Results showed that icon size, the number of icons on a display, and background color affected search strategies as participants identified one target icon among non-target icons. Specifically, as icon size decreased and the number of icons increased, scan time increased for participants with AMD. Although the results for the group without AMD were not significant, the performance trend was the same as that discussed for participants with AMD. This finding shows that icon size and clutter are important design factors for user populations with different visual needs. Smaller elements and screen clutter may also cause Soldiers to spend too much time focused on a display while attempting to discriminate and interpret information. Such behavior would distract the Soldier's attention from battlefield events in the immediate environment. Designing displays where visual information is presented to facilitate understanding should reduce this risk to optimal performance (Lee, Forlizzi, & Hudson, 2005). These results show the importance of concurrent system and user evaluations to document the human-computer interaction relationship. For new and changing displays, an evaluation should be conducted to determine how best to integrate current symbol sets with new electronic platforms so that symbols and display size are compatible with the user's visual abilities and limitations (National Research Council, 1983). Specifically, it is important to evaluate those factors affecting symbol perception (Pond, 1988), so the display environment is not a factor that contributes to a decrease in visual performance.

Thus, this research effort focused on two factors considered to be an issue when one is identifying symbols on small displays. Symbol size and screen clutter[2] were investigated to evaluate their effects on symbol identification when one is using a small display.

2. Method

This research consisted of two experiments. The purpose of experiment 1 was to determine the minimum resolvable symbol size for a group of selected symbols that could be discriminated and identified on a simulated wrist-mounted display. The purpose of experiment 2 was to determine the number of symbols that could be displayed on a simulated wrist-mounted display without significant decreases in performance.

2.1 Experiment 1: Symbol Size Threshold

2.1.1 Apparatus and Symbols

An actual wrist-mounted display was not used for this study. A standard Dell computer (using Windows[3]2000) and a 17-inch monitor with a resolution of 1600 x 1200 pixels were used to

[2]Several different names and definitions for clutter exist in the literature. For this discussion, clutter was defined as "the number of characters [items] displayed" (Tullis, 1983).

[3]Windows is a trademark of Microsoft Corporation.

simulate the size and resolution of a wrist-mounted display environment[4]. (The monitor selected for this study was required to match [or exceed] the resolution requirement of the proposed wrist-mounted display.) The unused portion of the screen was set to a black background, thereby creating the illusion of a small display with the use of the window dimensions of the proposed wrist display. The mouse was used as the response interface. A chin rest was used to control participant's head movements and the viewing distance (12 inches) from the computer monitor. Although pilot tests revealed that participants were comfortable at a viewing distance of 12 inches, the maximum recommended viewing distance for a 3.5-inch display is 14 inches (http://www.myhometheater.homestead.com/viewingdistancecalculator.html#anchor_13194).

Fourteen symbols were chosen from Field Manual (FM) 101-5-1 (Department of the Army, 1997) as stimuli for this experiment (figure 1). FM 101-5-1 provides guidance to the Army on matters pertaining to land-based war-fighting symbology. The symbol information in FM 101-5-1 is also presented in MIL-STD-2525B (DoD, 1999). When choosing symbols to use in this study, the author consulted a military expert to ensure that the chosen symbols would be symbols likely to be used by infantry Soldiers. Each symbol from the universal list of infantry symbols was assumed to have a unique acuity threshold value that was different from all the other symbols on the list. Because of this, acuity threshold differences attributable to symbols were not of interest. Individual symbol differences most likely reflected factors that were inherent in the symbols themselves (i.e., symbol uniqueness) which is why a technique was needed to relate the symbols on some level. In an attempt to generalize the findings from this experiment to other symbols in MIL-STD-2525B, two symbol density categories were created. Symbols were chosen in pairs, seven less dense symbols and seven dense symbols. For each less dense symbol, a similar dense symbol was chosen. Paired symbols were deemed physically similar if, when the content or features were removed from the dense symbol, it resembled the less dense symbol of the pair. The categories were created on the basis of the number of features needed to create the symbol. Generalizations could then be made according to symbol features for the remaining infantry symbols that were not chosen for this experiment. All symbol presentation and participant response recording were programmed to run autonomously with the programming language Delphi[5]. All symbols were black and were shown on a no-map or map background. Symbol size (i.e., stimulus intensity) was measured in "points". "In typography, a point is about 1/72 of an inch and is used to measure the height of characters" (www.webopedia. com/TERM/P/point.html). "Point" size corresponds to True Type font sizes in Microsoft Office[6] programs. Therefore, the manipulation of symbol sizes in this study followed the same "point" scale as text size fonts in Microsoft Word.

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[4]The 17-inch monitor (1600 x 1200) and the proposed 3.5-inch wrist display (320 x 240) both contain a pixel density of 115 pixels/inch. Those pixels required to match the resolution of the wrist display could be used when an area of the CRT is limited to an area comparable to the wrist display. Therefore, all the available pixels for the CRT monitor were not used.

[5]Delphi is a trademark of Borland Corporation.

[6]Office and Word are trademarks of Microsoft Corporation.

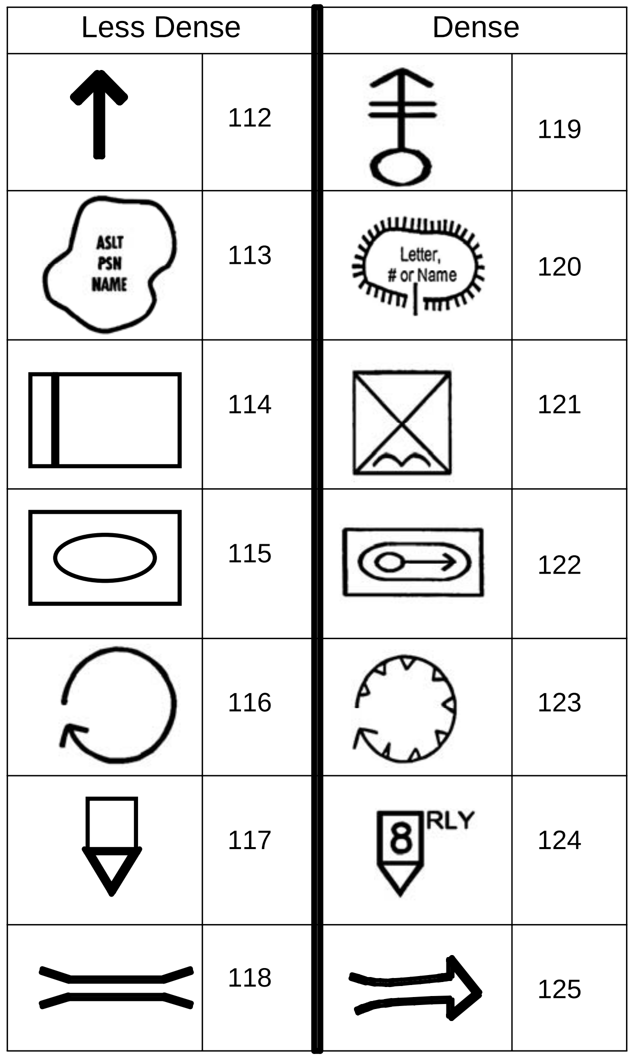

Figure 1. Less dense and dense symbols arranged with assigned numbers. (The numbers were assigned as identifying character codes similar to those shown in the symbol template retrieved via the Word "Insert" menu.)

2.1.2 Symbol Size Threshold Measurement

To determine symbol size thresholds (i.e., the smallest size of a symbol at which an observer can see and identify the symbol) for each symbol, the Best PEST (Parameter Estimation by Sequential Testing) psychophysical adaptive procedure was used. Best PEST is an alternate measurement procedure to the "staircase" method. Best PEST is more efficient in that a smaller number of trials are needed to find the threshold, which also reduces the amount of time participants are needed for testing. The staircase method is one of a few psychophysical methods that fail in efficiency because of the need to accumulate a good amount of information, but it does not gain any more information than if an adaptive procedure were used (Harvey Jr., 1986; Pentland, 1980). The Best

PEST procedure is also slightly more accurate at estimating sensory thresholds (Ehrenstein & Ehrenstein, 1999).

To obtain the greatest efficiency from the Best PEST procedure, it is often suggested that preliminary tests be conducted to determine the most appropriate stimulus intensity range. Preliminary testing allows the experimenter to estimate the threshold to narrow the stimulus intensity range around that estimated threshold. This alleviates the Best PEST procedure from presenting stimulus intensities that are too far from the true threshold. Only stimulus intensities near the true threshold provide relevant information (Ehrenstein & Ehrenstein, 1999), which allows the experimenter to use a very small number of trials to find the true threshold. To obtain a symbol size range containing a minimum and maximum symbol size value, preliminary tests were conducted to find estimated threshold values for each of the 14 symbols using the "method of adjustment". For the method of adjustment, a symbol is presented to an observer and the observer increases or decreases the symbol size until the symbol is barely able to be seen (Gescheider, 1997). Professional colleagues participated in preliminary tests using the method of adjustment. Each colleague viewed each symbol ten times on both the no-map and map backgrounds. After symbol size thresholds were found for each symbol, the symbol size range was constructed to include symbol size values found for the no-map and map display environments. Each obtained symbol size value was listed once to construct a number series and the median was found. The symbol size range was then balanced to the left and right of the median value with a scale of ±15 points (in increments of 1 point). The symbol size range for this experiment was set to 1 point as the minimum value and 30 points as the maximum value. The Best PEST procedure was programmed to vary symbol size values within this range.

The Best PEST procedure was used to find threshold values for each of the 14 symbols. Each symbol was presented ten times in randomized order. An arbitrary symbol size value within the symbol size range was presented on the first trial. The procedure operates so that if the observer's response is incorrect, a larger symbol size is presented on the next trial. In contrast, if the observer's response is correct, a smaller symbol size is presented on the next trial. With the observer's response from the first trial, the procedure begins the process of evaluating where the true threshold might fall via the "maximum-likelihood" method. This method calculates new estimates for symbol size values likely to be the true threshold and chooses the symbol size estimate that statistically maximizes the probability of its being the true threshold (Treutwein, 1995). The chosen symbol size estimate is then presented for trial 2. The observer's responses from trials 1 and 2 are considered by the maximum-likelihood method, and a new symbol size estimate is presented for trial 3. This sequence is repeated for every trial until the last response is collected. Because Best PEST thresholds are based on an observer's past performance, the procedure is able to estimate thresholds very quickly. For specific details about Best PEST, see Lieberman and Pentland (1982), Pentland (1980), and Treutwein (1995).

Besides being efficient, the maximum-likelihood method allowed for the construction of a psychometric function. A psychometric function is a graphical depiction that plots the

probability of a correct response (ordinate) versus symbol size (abscissa). Threshold is usually defined as the symbol size that corresponds to the probability of obtaining 50% correct responses. This is the point at which half the responses are correct and half are incorrect. However, the psychometric function also shows correct response performance at probabilities other than 50%. For this study, reported threshold values corresponded to the value on the psychometric function that predicted the probability of obtaining 95% correct responses.

Finally, this experiment was not only concerned with obtaining symbol size thresholds at detection but was also concerned with reporting thresholds at which symbols could be discriminated from one another. Most psychophysical methods only require an observer to report if s/he sees a stimulus or does not see a stimulus. If a stimulus is present, often there is no verification that an observer actually sees the stimulus or is making a correct guess (Ehrenstein & Ehrenstein, 1999). The "forced-choice" procedure requires participants to identify some specific characteristic about the presented stimulus (e.g., location, orientation) on each trial (Ehrenstein & Ehrenstein, 1999). A correct response is inferred if the characteristic is identified. This study used a 14-alternative forced-choice paradigm which corresponded to the 14 symbols chosen for this study. For each trial, a symbol was presented above or below threshold size, and participants responded by clicking on the symbol (from a list of 14) they believed was currently displayed. If an incorrect symbol was chosen, it was assumed that the participant could not discriminate the features of the symbol clearly enough to identify it from the other available symbols. If the correct symbol was chosen, it was assumed that the participant could discriminate enough symbol detail to identify the symbol from the other available symbols.

2.1.3 Experimental Design

A 2 x 14 mixed design was used to describe the data collection process. Environment, a between-subjects variable, consisted of two levels: no map and map. Symbol, a within-subjects variable, represented the 14 symbols shown in figure 1. Symbol presentation order was randomized for each participant. Symbol size threshold was the dependent variable measure.

2.1.4 Participants

Twenty Soldiers, ages 18 to 35 (M = 21.2 years), participated in this experiment. Participants were required to have at least 20/40 visual acuity in each eye (corrected or uncorrected), stereopsis, and normal color vision to participate. A vision test was administered to ensure that each participant met all vision criteria. Participants were randomly assigned to the no-map environment or the map environment for a total of ten participants in each group. Informed consent was obtained from each participant before testing.

2.1.5 Procedures

Participants were presented with a number of images that consisted of either a no-map or map background. Each image contained one symbol and the symbol appeared in the same place for every image presented (figure 2). For each image presented, participants were asked to demonstrate that they could discriminate the details of a symbol by choosing that symbol from a group of 14 symbols listed to the right of the image. To choose the symbol, the participant clicked on the symbol contained in the list. The Best PEST procedure operated so that for some trials, the symbol was clearly visible and identification of the symbol was assumed to have occurred with no difficulty. For other trials, the symbol was presented below threshold, and it was assumed that participants would have difficultly in identifying the symbol. For those trials where the symbol was presented below threshold, participants were instructed to make a best guess when choosing from among the 14 symbols listed to the right of the image. Four practice trials were given before actual testing began. Each of the 14 symbols chosen for this study was presented 10 times for a total of 140 trials to complete the experiment. When the study was completed, participants were debriefed and any questions asked by the participants were answered.

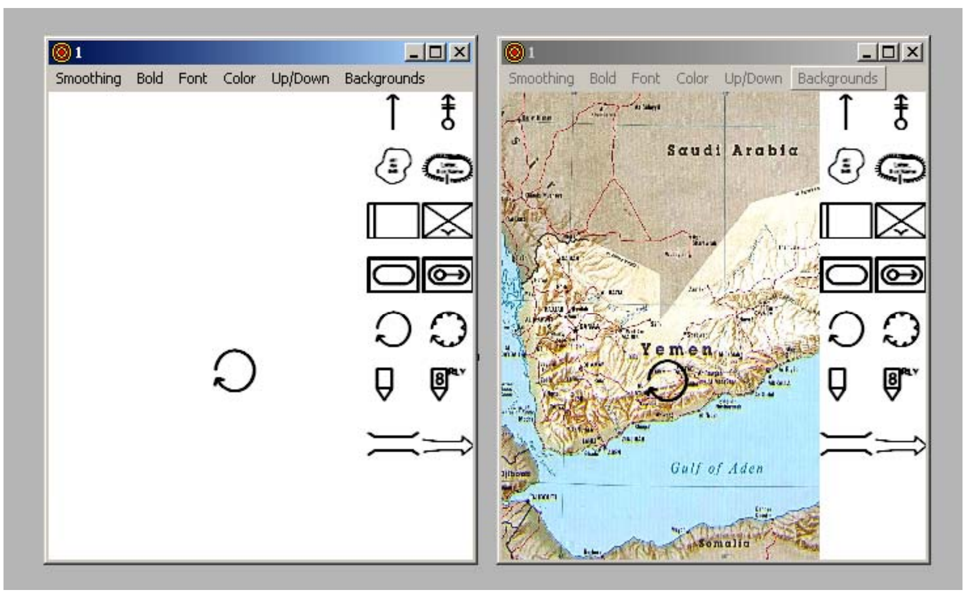

Figure 2. Examples of the no-map and map environments (not drawn to scale).

2.1.6 Results and Discussion

The data in table 1 show the mean symbol size threshold values for the no-map and map display environments. A *t*-test comparison revealed that symbol size threshold values were significantly higher for the map display environment (M = 13.06) than for the no-map display environment (M = 9.47), $t(10) = 6.58$, $p < .00006$. Thus, symbol identification was much more difficult when the symbols were displayed in the map display environment. Symbol details that could be seen in the no-map display environment became obscured by the topographical details within the map display environment. An analysis of the data in table 1 shows that symbol size values varied

significantly more in the map display environment (standard deviation [SD] = 1.67) than in the no-map display environment (SD = .41), $F(1, 18) = 5.99$, $p < 0.025$[7]. The large variation in symbol threshold values within the map display environment shows the degree of uncertainty experienced by observers when they were identifying symbols in that environment. The Best PEST procedure shows this because it measures threshold by presenting a larger symbol size when the observer is uncertain about a symbol, which is indicated by an incorrect answer. In the map display environment, participants could not identify the symbols in the same sizes that were presented in the no-map display environment. Sensing observer uncertainty in the map environment, the Best PEST procedure increased symbol size values until observers were able to discriminate and recognize symbols with some degree of certainty.

Table 1. Mean (standard deviation) symbol size threshold (in points) by environment.

Symbol	**112**	**113**	**114**	**115**	**116**	**117**	**118**	**119**	**120**	**121**	**122**	**123**	**124**	**125**
No Map	9.2 (1.6)	10.5 (1.7)	8.4 (.84)	10.1 (2.5)	8.8 (.79)	9.7 (1.8)	8.9 (1.7)	9.5 (.85)	9.5 (1.2)	8.9 (.99)	7.9 (.88)	11.4 (1.5)	8.1 (.88)	11.7 (.67)
Map	13.8 (2.9)	16.9 (3.7)	12.2 (2.8)	11.9 (2.1)	13.6 (5.9)	13.6 (3.3)	11.1 (1.9)	14.1 (2.2)	13.8 (2.4)	11.2 (1.7)	10.6 (2.6)	13.9 (1.7)	11.6 (2.0)	14.5 (1.9)

Despite the map display environment reporting higher symbol size threshold values, as well as a wider range of size values around the mean symbol size threshold, a symbol size threshold value of 16 points is recommended for discrimination and identification among symbols in this study. The symbol size threshold of 16 points corresponded to the largest mean symbol size (across participants) measured for any one symbol. Two symbols in the no-map display environment had mean symbol size thresholds of 11 points—the highest symbol size in that environment. One symbol in the map display environment had a mean symbol size threshold of 16 points—the highest symbol size of both display environments.

2.1.6.1 Symbol Density

This study had no interest in evaluating symbol size threshold values attributable to differences among symbols, only differences attributable to the display environment. However, the symbols were of interest when grouped according to two density levels. A paired sample *t*-test comparison of symbol size threshold values between symbols grouped as less dense and symbols grouped as dense (figure 1) showed no significant differences in symbol size threshold between the two groups.

Table 2 shows that symbol size threshold values were not affected by the density characteristics within a symbol but by the background of the display environment. Lindberg and Näsänen (2003) stated that reducing the size of a symbol that contains a number of features will make the symbol more difficult to identify. According to the results of this study, this statement would only be true if the symbol were presented below threshold. If a symbol is always presented at or

[7]Levene's Test for Equality of Variances.

above visual threshold, the observer should not have a difficult time when asked to identify the symbol. Regardless of the number of features needed to construct a symbol, if the symbol is presented above threshold and placed on a background that will strengthen the contrast between the symbol and the background, the circumstance for symbol identification should be ideal. The current study limited the degree of density allowed within a given symbol. However, in MIL-STD-2525, there are infantry symbols with higher symbol densities than those used in this experiment. Furthermore, no significant difference was found between the thresholds obtained for the symbols of varying density used in the present study. Therefore, it cannot be concluded with a high degree of certainty that symbol size threshold is not affected by the number of features in a symbol.

Table 2. Mean (standard deviation) symbol size threshold values (in points) by symbol density and environment.

Symbol Density	Environment	Mean
Dense	Map	12.81 (1.6)
	No Map	9.57 (1.5)
	Total	11.19 (2.3)
Less Dense	Map	13.30 (1.9)
	No Map	9.37 (.76)
	Total	11.34 (2.5)

2.2 Experiment 2: Screen Clutter and Performance

2.2.1 Apparatus and Symbols

The equipment used to simulate the wrist display in experiment 1 was also used to simulate the environments in this experiment (see section 2.1.1). The 14 symbols used in experiment 1 were also used for this experiment as targets and distractors[8]. Target and distractor symbols were shown at a symbol size of 16 points. The symbol size selected for use in experiment 2 was the largest of the 95% threshold value from each of the 14 symbols across environments in experiment 2. A map image containing three or six symbols was designated as a low clutter display. A map image containing 9 or 12 symbols was designated as a high clutter display.

2.2.2 Participants

Eight Soldiers, ages 18 to 35 (M = 22.9 years), participated in this experiment. Participants in this experiment were different from the participants in experiment 1. Participants were required to have at least 20/40 visual acuity in each eye (corrected or uncorrected), stereopsis, and normal

[8]Because of the unique quality of each symbol, each symbol was expected to have its own size threshold value at which it could be seen. A different set of symbols may not have had the same threshold value as the symbol set in experiment 1. Symbols with a threshold value higher than what was found in the previous experiment would be barely visible. The threshold value found in experiment 1 minimized the chance that symbol size would be a confounding factor for this experiment.

color vision to participate. A vision test was administered to ensure that each participant met all vision criteria. Informed consent was obtained from each participant before testing.

2.2.3 Procedures

Participants were presented with 80 images that consisted of a rural or urban map display environment (figure 3). Each map contained a different number of symbols consisting of those in figure 1. The number of symbols embedded on each map, at any time, was varied among 3, 6, 9, or 12 symbols. For each image presented, participants were instructed to search for and identify one target symbol, which was shown before the image was presented. The target symbol always resided outside the map environment and to the right of the display screen for the duration of a trial. The display of the target symbol for the duration of a trial helped to alleviate problems with participants failing to recall the target in the midst of a search. The target symbol did not always appear on the map (50% of the trials). If the target symbol was present on the map, the participant was instructed to click on the symbol within the map environment. If the target symbol was not present on the map, the participant was instructed to indicate this by clicking a red "not-present" symbol that also resided outside the map environment and to the right of the display screen. The red symbol (symbolizing that the target was not present) was always positioned next to the target symbol and remained in that position for the duration of the experiment. While the target symbol changed from trial to trial, the red not-present symbol always remained the same. When participants clicked on the target symbol within the map or the red not-present symbol outside the map environment, the scan time was recorded and the current trial ended and the next trial began. Four practice trials were given before actual testing began. When the study was completed, participants were debriefed and any questions asked by the participants were answered.

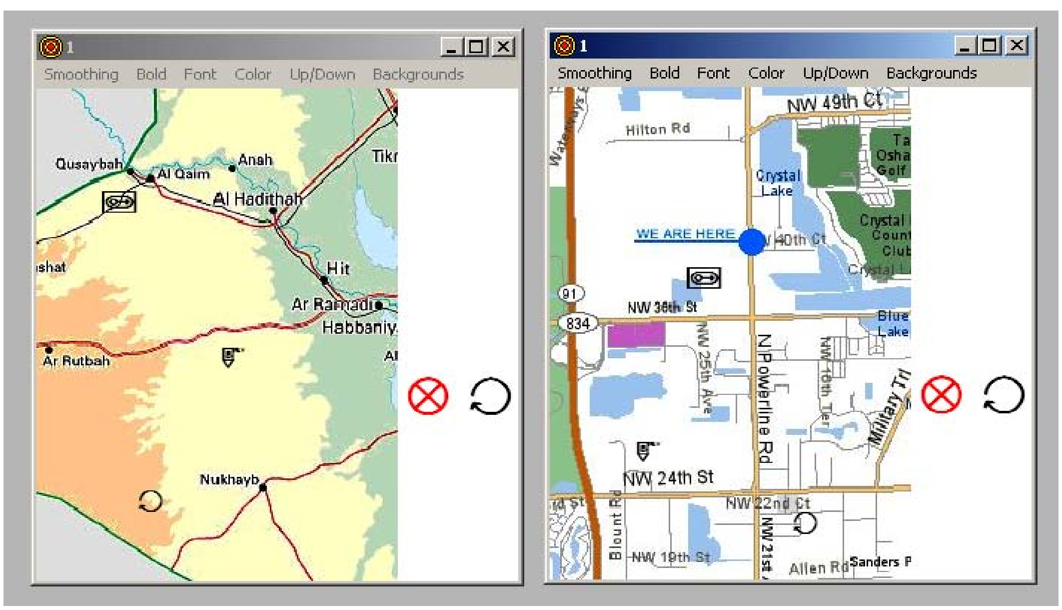

Figure 3. Images presented in the rural (left) and urban (right) map display environments (not drawn to scale). (The not-present symbol is the symbol on the left and the target symbol is the symbol on the right.)

2.2.4 Experimental Design

Environment and clutter were the independent variables for this experiment. Environment consisted of a rural map display and an urban map display. Clutter consisted of 3, 6, 9, and 12 symbols. Stimuli consisted of 80 map images. Forty map images were shown for each environment level. Ten images were shown at each clutter level. For each clutter level, five images contained a target symbol and five did not contain a target symbol. To build the images according to clutter level, when a target symbol from figure 1 was present, some combination of the remaining 13 symbols served as distractors. For example, if three symbols appeared on an image, one symbol from figure 1 was designated the target and the remaining two symbols (randomly chosen from figure 1) served as distractors. When a target symbol was not present, some combination of the 14 symbols from figure 1 served as distractors. For example, if 3, 6, 9, or 12 symbols appeared on an image, all symbols (randomly chosen from figure 1) on the image served as distractors. All symbols were randomly placed on each map without overlapping each other.

2.2.4.1 Errors and Penalties

There were four categories of errors in this experiment: (1) participant clicked on wrong symbol as the target symbol, (2) participant indicated that the target symbol was present when it was not (false alarm), (3) participant indicated that the target symbol was not present when it actually was (miss), and (4) participant required more than 60 seconds to make a response. All errors were assessed a time penalty and each type of error was assessed a different time penalty. Categories 1 and 2 were assessed a penalty of 15 seconds, category 3 a penalty of 30 seconds, and category 4 a penalty of 45 seconds. For each response, it was possible for participants to be penalized twice. One penalty was assessed if an error of category 4 was committed, with an additional penalty added if the response was incorrect (an indication that an error of category 1, 2, or 3 occurred). A chi-square test was used to evaluate if error category depended upon display environment and clutter.

2.2.4.2 Response Accuracy

Response accuracy was also of interest. Response accuracy was defined as the total number of correct and incorrect responses. A correct response was recorded if the participant identified the target symbol correctly in those maps with a target symbol or for noting that the target symbol was not present in those maps without a target symbol. A chi-square test was used to evaluate if response accuracy depended upon display environment and clutter.

2.2.4.3 Data Analysis

A 2 x 4 within-subject analysis of variance was used to evaluate the effects of environment (rural map display, urban map display) and clutter (3, 6, 9, and 12 symbols) on scan time. Clutter corresponded to the number of symbols that were shown concurrently on a map. Scan time was

recorded as the time participants expended to decide if a target symbol was present or absent. Scan time was measured from the time the map image first appeared to the time participants clicked the mouse button to indicate a decision for the current trial. All symbol presentation and participant response recording was programmed to run autonomously with the programming language Delphi. The data were automatically sent to a spreadsheet. The final scan time included the actual scan time plus any additional time penalties assessed for errors. Data analyses were based on the final scan time. The presentation order of treatments was randomized for each participant.

2.2.5 Results and Discussion

An analysis of scan time indicated significantly longer scan times in the urban map display environment (M = 13.28 s) than in the rural map display environment (M = 8.97 s), $F(1, 632) = 13.24$, $p < .0001$. No significant effects were found for clutter or the interaction of display environment and clutter. A Fisher's least significant difference (LSD) *post hoc* comparison among the four clutter levels revealed scan time differences between clutter levels of 3 and 12 symbols. The mean difference observed between clutter levels of 3 and 12 symbols in the rural map display environment was 1 s and 6.2 s in the urban map display environment. In the urban map environment only, the mean scan time began to increase at the clutter level of 9 symbols and continued to increase at a clutter level of 12 symbols (figure 4). On average, participants required 11 s of scanning time to determine the presence or absence of a target symbol.

These results show that clutter (the number of symbols simultaneously appearing on an image), as defined for this project, does not affect scan time performance until it reaches the higher levels and only in the urban map display environment. Topographic clutter, which is a characteristic of every map, is higher for the urban map as opposed to the rural map. The combination of an increased number of symbols and the topographic clutter in the urban map may have resulted in an increase in scan time. This finding agrees with other such studies in the literature (Tullis, 1983), which conclude that an increase in display clutter beyond what is relevant will cause a decrement in performance. However, the significantly longer scan times found for the urban map display environment show that background clutter can affect performance by itself. An increase in the amount of background clutter increases the time it takes to discriminate and identify symbols. This appears to be true even if the symbols are presented above the visual size threshold for that background.

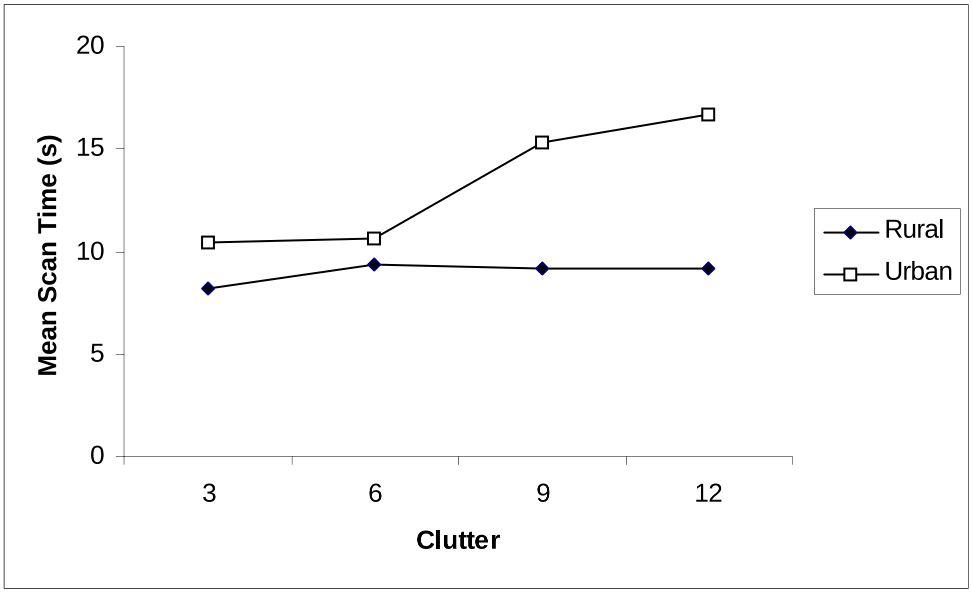

Figure 4. Mean scan time performance at each of the four clutter levels for the rural and urban map display environments.

2.2.5.1 Response Accuracy

Of the 640 responses collected in this experiment, 589 (92%) of the responses were correct and 51 (8%) of the responses were incorrect. Response accuracy had no dependence upon clutter or display environment. This finding was expected because the symbols were shown at the 95% size threshold of 16 points. The map display environment from experiment 1 was comparable to the urban map display environment in experiment 2. It was expected that most incorrect responses would reside at the higher levels of clutter. However, this was only the case for the urban display environment (table 3). As discussed for the analyses of scan time, the combination of an increased number of symbols and topographic clutter in the urban map likely produced the larger number of incorrect responses. The number of incorrect responses was essentially the same at the low and high clutter levels for the rural display environment. Overall, the number of incorrect responses increased as clutter level increased.

Table 3. Classification of incorrect responses by environment and clutter.

Environment		**Clutter**				**Total**
		3	**6**	**9**	**12**	
Rural	Count	1	6	2	5	14
	Percent of Total	2	11.8	3.9	9.8	27.5
Urban	Count	6	4	14	13	37
	Percent of Total	11.8	7.8	27.5	25.5	72.5
Total	Count	7	10	16	18	51
	Percent of Total	13.7	19.6	31.4	35.3	100

2.2.5.2 Errors

Of the 55 errors made, 1 (1.81%) was of category 1 where the participant identified the wrong symbol as the target, 25 (45.46%) were of category 2 which was a false alarm, 25 (45.46%) were of category 3 which was a miss, and 4 (7.27%) were of category 4 where the participant did not make a decision within 60 s. The type of error had no dependence upon clutter or display environment. There were more false alarms and misses than any other type of error. The number of false alarms and misses were equal and no clear pattern emerged within or across the levels of clutter and display environment. The randomness with which symbols were chosen to appear together as well as where symbols were arranged on the maps, may be attributable to false alarms and misses falling randomly across treatments. The false alarms committed in this experiment may have occurred because of the similarity among some of the symbols. The misses may have occurred because symbols possibly appeared in places on the maps where topographic details may have distorted details in the symbols.

Errors were assigned penalties based on their degree of consequence. Errors of category 1 and 2 were given the lesser penalty because the observer would be moved to action in response to a real or believed stimulus. Errors of categories 3 and 4 were given higher penalties because no action would be taken if a real stimulus were presented. On the battlefield, neither false alarms nor misses are desired, but if an error is inevitable, a false alarm may be more desirable. Both have the potential for injury and death as a consequence. If a symbol (which represents information) is falsely believed to be present, some erroneous action may be taken which may lead to injury or the death of fellow Soldiers. On the other hand, if a symbol is missed completely, information signaling danger may lead to injury or death for the Soldier or team that missed the information. Although there was a very small number of errors, the consequences associated with false alarms and misses might make it a priority to reduce them further.

3. Conclusions

The first goal of this research effort was to recommend the minimum resolvable symbol size for a simulated, 3.5-inch wrist-mounted digital map display. Common military symbols used to communicate critical battlefield information were considered. For the wrist-mounted map display, a symbol size of 16 points was found to match the visual capability (i.e., user can discriminate and identify symbols) of a user with at least 20/40 visual acuity viewing the display at a distance of 12 inches. The positive impact of using this symbol size was demonstrated in experiment 2 via participant performance in obtaining 92% response accuracy when participants were identifying a target symbol among distractors on a map background. Overall, evidence showed that a 16-point symbol was clear, distinctive, and identifiable for map use. For instances

when information will be displayed on a no-map and white or light background, a symbol size of 12 points can be used.

The second goal of this research effort was to recommend the number of symbols that could be displayed on the wrist display before there was a noticeable decline in performance. The background and foreground content of the display emerged as important factors that should be evaluated when one is making a decision pertaining to the number of symbols that could lead to display clutter. If the map background does not perceptibly contribute to display clutter, superimposing as few as three or as many as 12 symbols over the map will yield no change in scan time (i.e., time needed to make a decision) for a target symbol. However, if the map background does contribute to display clutter, increasing the number of symbols on the map will increase scan time, which may be detrimental to the Soldier's mission. The results obtained from this research effort showed that the number of symbols alone did not affect performance. Particularly, performance did not decline for display conditions when there was little or no background content to contribute to clutter. For these conditions, the use of clutter levels beyond that of 12 symbols may be feasible for this size display without causing a decline in performance. If the wrist display will also be extensively used for no-map applications, it is suggested that further work be done to identify the number of symbols at which performance will begin to decline.

3.1 Color

Color was not used as a factor in the present study because the graphical user interface intended for use with the wrist-mounted display was not determined at the time of this study. Without knowledge of the final display colors, light map backgrounds were chosen for the high contrast provided when used with bold black symbols. The high contrast between the foreground and background may have helped to contribute to the low error rate of 8%. Most of the errors were false alarms and misses, and presenting the symbols in color may be beneficial in reducing these errors. According to Wickens and Rose (2001), color may be the best method for highlighting symbols during a visual search task. Because color is a factor that is capable of "drawing attention" (Sanders & McCormick, 1993), it could be used to increase symbol contrast and reduce symbol distortion attributable to map features thought to be the cause of misses in this experiment. The theory behind designing two or more military symbols that have relatively similar features is to make identification and classification easier for symbols within the same class (such as tanks) (Jarosz & Rogers, 1982). For this situation, color may be used to make symbols with similar features more distinctive when they appear together, thus reducing the number of false alarms. In addition, the use of color symbols has the potential to lower the symbol size threshold without affecting the user's ability to discriminate and identify symbols if more workable screen space is required.

3.2 Trade-offs

The consideration of trade-offs to make a system as efficient as possible is a vital part of equipment design. Based on the results from this study, is a 92% accuracy rate acceptable for the wrist-mounted display? If not, suggestions about how to increase the accuracy rate are discussed and the foreseeable effects that it would have on false alarms and misses are also discussed. Trade-offs come with consequences, and acceptable trade-offs will depend on those factors that will most likely optimize human performance. For example, as an alternative to using color symbols, reducing the number of misses could be addressed by increasing the symbol size. Increasing the symbol size would increase the contrast of the symbol against the background of the map (Sanders & McCormick, 1993). Obtaining the larger symbol size would need to be based on criteria so that a tolerable rate of incorrect responses would be less than the current rate of 8%. However, increasing the symbol size would come with the price of possibly losing essential screen space.

Soldiers are tasked with the responsibility of taking information from the environment and using that information to make quick and accurate decisions in response to the dynamically changing battlefield. Such decisions may often determine life or death and should be used as a guideline to define acceptable limits of consequence from system use. Therefore, it is imperative that battlefield information be displayed to the Soldier in a legible and organized format which will help to increase the Soldier’s (situational) understanding of his environment and decrease the amount of time the Soldier devotes to gathering information for critical decision making.

4. References

Barnes, M. J. *The Human Dimension of Battlespace Visualization: Research and Design Issues*; ARL-TR-2885; Army Research Laboratory: Aberdeen Proving Ground, MD, 2003.

Carstens, C. *LW-Rapid Fielding Initiative Side by Side Evaluation*. Personal Briefing Notes, Fort Benning, GA, December 2004.

Christie, B.; Scane, R.; Collyer, J. Evaluation of human-computer interaction at the user interface to advanced IT systems. In J. R. Wilson and E. Nigel Corlett (Ed.), *Evaluation of Human Work: A Practical Ergonomics Methodology* (2nd ed., pp. 310-356), Bristol, PA: Taylor & Francis, 1995.

Department of the Army. *Operational Terms and Graphics*; Field Manual No. 101-5-1; Washington, DC, 30 September 1997.

Department of Defense. *Interface Standard: Common Warfighting Symbology*. MIL-STD-2525B, Washington, DC, 30 January 1999.

Department of Defense. *Transformation Trends*, May 4, 2004. Office of Force Transformation. http://www.oft.osd.mil/.

Durbin, D. B.; Armstrong, R. N. *Abbreviated Assessment of Three Moving Map Displays for the UH-60 Helicopter*; ARL-TN-174; Army Research Laboratory: Aberdeen Proving Ground, MD, 2000.

Ehrenstein, W. H.; Ehrenstein, A. Phychophysical Methods. In U. Windhorst and H. Johansson (eds), *Modern Techniques in Neuroscience Research*, pp. 1211-1241. Berlin: Springer-Verlag, 1999.

Endsley, M. R. Towards a Theory of Situation Awareness in Dynamic Systems. *Human Factors* **1995**, *37* (1), 32-64.

Gescheider, G. A. *Psychophysics: The Fundamentals* (3rd ed.). Erlbaum: Mahwah, NJ, 1997.

Gourley, S. Individual Soldier Systems – Future Warrior. *Jane's Defence Weekly*, October 20, 2004.

Harvey Jr., L. O. Efficient Estimation of Sensory Thresholds. *Behavior Research Methods, Instruments, & Computers* **1986**, *18* (6), 623-632.

Jacko, J. A.; Barreto, A. B.; Scott, I. U.; Chu, J.Y.M.; Vitense, H. S.; Conway, F. T.; Fain, W. B. Macular Degeneration and Visual Icon Use: Deriving Guidelines for Improved Access. *UAIS* **2002**, *1*, 197-206.

Jarosz, C. J.; Rogers, S. P. *Evaluation of Map Symbols for a Computer-Generated Topographic Display: Transfer of Training, Symbol Confusion, and Association Value Studies*; DAVAA-TR-81-0089-5; U.S. Army Avionics R&D Activity, 1982.

Lee, J.; Forlizzi, J.; Hudson, S. E. *Studying the Effectiveness of MOVE: A Contextually Optimized In-Vehicle Navigation System*. CHI 2005. 571-580, ACM Press: Portland, OR, 2005.

Lieberman, H. R.; Pentland, A. P. Microcomputer-Based Estimation of Psychophysical Thresholds: The Best PEST. *Behavior Research Methods & Instrumentation* **1982**, *14* (1), 21-25.

Lindberg, T.; Näsänen, R. The Effect of Icon Spacing and Size on the Speed of Icon Processing in the Human Visual System. *Displays* **2003**, *24*, 111-120.

National Research Council. *Tactical display for Soldiers: Human factors considerations*. National Academy Press: Washington DC, 1997.

National Research Council. *Video Displays, Work, and Vision*. National Academy Press: Washington DC, 1983.

Pentland, A. Maximum Likelihood Estimation: The Best PEST. *Perception & Psychophysics* **1980**, *28* (4), 377-379.

Pond, D. J. *Military Symbologies: An Overview and Select Annotated Bibliography*; Report HEL-TN-6-88; Human Engineering Laboratory: Aberdeen Proving Ground, MD, 1988.

Sanders, M. S.; McCormick, E. J. *Human Factors in Engineering and Design* (7th ed.). McGraw-Hill: New York, 1993.

Treutwein, B. Adaptive Psychophysical Procedures. *Vision Research* **1995**, *35* (17), 2503-2522.

Tullis, T. S. The formatting of alphanumeric displays: A review and analysis. *Human Factors* **1983**, *25* (6), 657-682.

U.S. Army Natick Soldier Center. U.S. Army Research, Development and Engineering Command (RDECOM). http://www.natick.army.mil/Soldier/WSIT/content.htm , March 2, 2005.

Wickens, C. D.; Rose, P. N. Human Factors Handbook for Displays: Summary of Findings From ARL's Advanced Displays and Interactive Displays Federated Laboratory, 2001.

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